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U.S. Department of Agriculture

RESEARCH ON INDUSTRIAL UTILIZATION OF CORN

With Special Reference to the Northern Regional Laboratory for Research on the Utilization of Farm Products

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Remarks by Dr. Henry G. Knight, Chief, Bureau of Agricultural Chemistry and Engineering, United States Department of Agriculture, before the Sixth Annual Chemurgic Conference, Chicago, Illinois, Wednesday afternoon, March 27, 1940.

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A year ago I talked before the 1939 Annual Conference of this organization. Then you were at Jackson, Mississippi, in the midst of the cotton belt. My subject was the New Regional Laboratories for Research on the Industrial Utilization of Farm Products. I gave special emphasis to an outline of some of those things we planned to investigate at the Southern Laboratory. Now you are here in Chicago, in the midst of one of the most productive agricultural areas in the world. In this area is produced the largest part of America's greatest crop, corn, the backbone of the agricultural economy of this region. This year a considerable percentage of the corn produced will be of high yielding hybrid varieties, and no doubt more of it than ever before will be harvested with mechanical pickers. You are visiting in a region where mechanization of agriculture and other improvements in farming practices have gone forward at a faster pace than in most other parts of the country. But even in the South, where the use of power on the farm has been more slowly developed, a unit of cotton or cane is now produced more easily than in the fairly recent past.

In view of the continuing trend toward more efficient crop production, the established recognition of the importance of research in opening up new outlets for farm products is a most encouraging sign. Over the past 50 years, the productive efficiency of agriculture in the country has been greatly increased chiefly because of mechanization, improved methods of tillage, better varieties of plants and steady progress in animal husbandry. Crop production per agricultural worker has increased nearly two and one-half times during the last 90 years and since 1920, 30 to 35 percent. This increased productivity has not been confined to the United States but has been developed to some extent in every agricultural country. It is plain that the chief advances in agriculture have been in the field of production as is also true to some extent of industry. However, industry has made great progress in expanding markets to keep pace with increased production, while the problem of better utilization of the products of the farm remains largely unsolved.

You have asked me to talk again about the four new regional laboratories for the utilization of farm products but I shall not repeat even in brief outline the preliminary plans for research in all of them. Since this meeting is taking place in what we call the Northern region I shall give attention to the Northern Laboratory now under construction at Peoria.

As a result of a survey made by a special committee of the Department of Agriculture, it was decided that in the beginning the Northern Regional Laboratory would direct its attention to problems dealing with the industrial utilization of corn, wheat, and crop residues, the latter the so-called agricultural wastes. Since corn is the most important commodity assigned for investigation to the Northern Regional Laboratory, it is only appropriate that the remaining time allotted to me be devoted to a discussion of this crop. In broad strokes, I will describe a picture of the agricultural background and the present industrial utilization of corn. Further, I will point out the problems confronting us in our investigations on starch, corn oil, corn proteins, motor fuels, and fermentations, which are the more important lines of research which we will undertake the develop new and extended uses for this commodity.

World production of corn has remained practically constant at 4 billion bushels since 1900. Of this, the United States produced about 68 percent prior to the World War, and about 60 percent in recent years. The Corn Belt, so-called, is the center of production, and consists of a broad belt from Nebraska eastward to central Ohio. For many years the United States has grown about 100 million acres of corn each year. In the last few years, however, this acreage had dropped to about 94 million. The domestic corn crop usually has ranged from about 2.5 to 3 billion bushels, the average yield per acre being in the neighborhood of 24 to 28 bushels for the country as a whole.

Although about 90 percent of the corn crop is utilized for animal feeding on the farms where it is grown, that portion of the crop which has been sold has brought farmers a cash income of about 250 million dollars for each of the past 2 years. The average disposal of the corn crop is as follows: Feeding hogs, 40 percent; feeding cattle and sheep, 24 percent; feeding horses and mules, 14 percent; other farm uses, 13 percent; and industrial and city uses, 9 percent. The replacement of power animals by motor power has decreased the demand for corn by about 4 percent of the total crop. Exportation of corn from the United States has been large in only a very few years. Record exports occurred in the year beginning October 1, 1929, when 168 million bushels were exported. Exports declined to an average of 6 million bushels during the 5-year period 1929-33. During the drought years 1934 to 1936 an average of 54 million bushels was imported. Then following the very small crop in Argentina, the United States exported 138 million bushels during the year beginning October 1, 1936, which was 5.2 percent of production.

In discussing the processing of corn, there is some question as to how the term "industrial utilization" may be defined. Using the term in its broadest sense as being applicable to that portion of the corn crop which enters processing industries, the amount used industrially is about 9 percent of the total crop. Of this percentage, about one-fourth is returned to the farmer in the form of byproduct feeds and one-half enters the food market. In other words, the actual percentage of the total corn crop which enters nonfood uses is very small.

Industrial products made from corn are largely starch and starch derivatives because, on the dry basis, starch makes up approximately 80 percent of typical corn kernels. The primary objective of both dry milling and wet milling of corn is to separate the endosperm, or starch-containing portion, from the hull or bran, and the germ, which is the oil bearing portion of the kernel. Both endosperm and germ contain protein. The corn dry-milling and corn wet-milling industries use more than 4/5 of the corn entering processing companies, the remainder being used in the manufacture of breakfast food, alcohol, and cereal beverages. More than 98 percent of all the starch produced in the United States, varying annually from 2 to 3 billion pounds, is made from corn, the remainder being prepared from wheat, rice, white potatoes, and sweetpotatoes. However, not all the starch consumed in the United States is of domestic production. In recent years imports of starches have increased markedly; in 1937 to as much as 484 million pounds. Tapioca and sago starch are imported in largest amounts, enter duty free, and sell somewhat below the price of the equivalent grades of cornstarch. Imported starches are not converted into dextrines, sirups, and starch sugar in this country and therefore are in more direct competition with domestically produced starch used as such. Of the starches sold and used in the form of starch, imports constituted 38 percent in 1937 and about 30 percent in 1938.

Approximately 1.2 billion pounds of starch are used annually as such. More than 75 percent is used for nonfood purposes, and less than 25 percent as food. The principal industrial uses of starch are found in the textile, dextrine and adhesive, papermaking, laundry, and wood manufacturing industries. Starch, in addition to being used as such, is also converted to empiric derivatives for food and industrial utilization and to glucose sirups, and dextrose. About one billion pounds of glucose sirups and a half-billion pounds of crystalline dextrose are produced annually. These two products are used mainly as foods.

Investigations on starch and starch derivatives may be divided into four classes: (1) Processing problems dealing with production of starch and starch derivatives; (2) studies on the food uses of starch and starch derivatives; (3) development of new industrial uses for starch and its derivatives, and of new products from starch, dextrines, or dextrose by chemical conversion; and (4) procurement of basic information on starch to provide a sound, rational, and logical basis in the search for new and extended uses of starch and its derivatives. The corn processing industries' research organizations, which are relatively small, have necessarily focused their activities on production problems and the first two types of investigations. Practically no attack has been made by industrial companies, universities, and the United States Department of Agriculture on the two last classes of research problems. These last two fields of work hold the most promise in extending the uses of corn, and are the ones in which the Northern Regional Laboratory can most fruitfully expend its efforts.

Practically no starch is chemically converted into materials having approximately the same or greater molecular complexity than starch itself, such as are prepared from the related carbohydrate, cellulose, which is used for the production of synthetic textile fibers, explosives, films, plastics, etc. Industrial surveys, the patent literature, and technical journals show that the experimental work carried out in this field has been exploratory and cursory. Even academic research dealing with the modification of starch to such derivatives as acetates, butyrates, etc., has been quite limited. The apparent lack of activity in this field is surprising as starch is probably the cheapest pure organic material available for industrial utilization. In view of its low price, starch has considerable promise for the manufacture of low-priced products having large volume uses. Likewise dextrose, because of its cheapness and reactivity is an attractive source of industrial raw material. Since its production on an industrial scale dating back to about 1925, little research work has been expended on the development of industrial uses for it. Within the last two years one industrial company has exploited with apparent success the properties and possible uses of the dextrose reduction products, sorbitol and mannitol, and one other has produced some well-known dextrose derivatives on a small scale, but for which there are as yet no extensive uses. Considerable pure research, however, has been devoted to the study of dextrose. Most of this work has been performed in order to ascertain the structure of dextrose and to establish its relationship to the other members of the sugar family, as well as to study its behavior towards chemical reagents not from the standpoint of industrial utilization but rather from theoretical considerations.

Progress in our knowledge of the sugars and starch in particular has been slow because of the handicaps associated with (1) the great difficulty in obtaining pure compounds by crystallization; (2) the lack of methods for obtaining structural information; (3) the difficulty in obtaining reaction with specific hydroxyl groups in large molecules; (4) the complexities introduced by isomerization phenomena; and (5) instabilities associated with the aldehyde group. The reactions involved in processing these materials industrially are depolymerization changes, hydrolytic reactions, oxidation reactions, and decomposition due to heat. The present methods of measurement used on modified starches and dextrines are generally arbitrary and have little significance outside of the industrial laboratory making the determination. Since the physical and chemical properties determine the industrial outlets, fundamental information regarding such properties is required to facilitate expansion in this field and to develop new uses. An extensive and long-time research program will, therefore, be conducted on the biological, physical, and chemical properties of starch granules, starch, modified starch, and dextrose as an essential basis for developing new and extended uses. Because of the excellent competitive positions of starch and dextrose in comparison with other refined raw materials on account of their price, and because of the tremendous supplies available, it seems almost inevitable that the acquisition and application of basic information on starch and dextrose should result in a wide expansion of their present industrial utilization.

Corn oil ranks third in volume of the vegetable oils produced annually in the United States. The potential supply, from an average annual corn crop of 2.5 to 3 billion bushels, exceeds that of any other vegetable oil source and approaches the entire domestic consumption of oils and fats combined. Development of fermentation alcohol for motor fuel or large increases in the industrial utilization of cornstarch such as are envisioned in the Regional Laboratory program would increase the quantity of available corn oil accordingly. For example, the use of 600,000,000 bushels of corn for power alcohol production would provide a potential byproduct corn oil supply of about one billion pounds.

More than 100 million pounds of corn oil are produced annually in the United States, most of which enters the edible oil field. The increased use of corn oil in competition with other surplus edible oils is technically the path of least resistance, but such increased use is ultimately destined to intensify the surplus edible oil problem. Fortunately, corn oil contains an exceptionally large proportion of chemically reactive linoleic acid glycerides, which may be adapted to uses dependent on polymerization phenomena. The utilization of this component of corn oil in surface coatings, rubber-like structural materials, flotation agents, adhesives, sprays, lubricants, and lubricant addition agents, etc., on a large scale is not an unreasonable expectation. Lack of knowledge relative to the composition and the required type and extent of modification necessary and the absence of practical processes for carrying out the modifications are largely responsible for the slight non-edible usage of corn and similar vegetable oils in our present oil economy. Investigations designed to overcome these difficulties will engage most of the attention that we expect to place on the development of new industrial uses for corn oil.

Protein residues are an inevitable byproduct of corn processing. Individual distilleries may produce over 100 tons per day of these residues, and starch manufacturers have comparable supplies. Any development which anticipates the extended use of cornstarch or corn oil must necessarily provide uses for the protein.

At present, protein residues from corn are quite largely marketed as stock feeds for which use they return from 1 to 2 cents a pound. Zein, the major constituent of the corn proteins, is now produced commercially. It can be obtained in yields of about 1.6 pounds per bushel of corn and currently sells for 20 to 25 cents a pound. Since Dr. Newkirk will discuss this field later in the program, further attention to it might well be deferred until then. Small amounts of corn proteins are used as a source of glutamic acid, the major amino acid of corn protein, which in the form of its sodium salt is used to enhance the meat flavor of certain food products. Other amino acids, such as leucine and tyrosine, are being produced commercially from corn protein. These latter derivatives are not likely to provide extensive outlets for corn protein. Large consumption must seek usage in the lower priced products requiring simple processing of less highly purified components. It is recognized that the behavior of these proteins varies considerably with the condition of treatment both before and during the processing operation. Data are not now available on methods for standardizing the quality or modifying the behavior of corn proteins isolated by the various processing methods. It is widely agreed among research directors in industrial laboratories that the expansion of protein utilization now awaits the accumulation of further fundamental information relative to proteins.

The fermentation industries of the country produce very considerable quantities of industrial chemicals as well as food, beverage, and medicinal products. The raw materials most used are blackstrap molasses, beet molasses, corn, and dextrose. Production of distilled spirits and fermented malt beverages consumes the major portion of the corn utilized by the fermentation industries. In the highly competitive field of production of industrial chemicals, manufacturers have turned from grains to cheaper sources of fermentable carbohydrate, such as beet or cane molasses and whey, and only relatively small quantities of dextrose are used, chiefly for the production of lactic acid, gluconic acid, and indirectly, in the production of sorbose.

Fermentation processes no doubt will play an important role in the more complete utilization of agricultural materials in the future. The many species of yeasts, bacteria, and molds which may be collected and identified differ widely in their ability to effect, under given conditions, chemical changes in the carbohydrates upon which they act. While higher organisms, such as man, usually oxidize carbohydrates completely to carbon dioxide and water, many micro-organisms only partially oxidize such substances and frequently realize less than 10 percent of the possible available energy. It is upon incomplete utilization of the carbohydrates supplied to them, varying enormously from organism to organism, that our fermentation processes are based. Many of these transformations are actually or potentially useful because they are brought about efficiently and produce one or more end products in good yields. Others are apparently useless because of the slow rate of transformation or inefficient conversion. The selection or discovery of the more desirable micro-organisms is therefore of great importance in the development of new and improved fermentation processes, and the best chance for success is afforded by the opportunity for testing and comparing a number of related strains and species gathered together and definitely identified in a representative collection. Such investigations of the chemical activities of various organisms lead not only to the discovery of the most suitable organisms to be employed for a desired fermentation but also may result in the discovery of new and unexpected products.

Obstacles are frequently encountered in fermentation investigations which apparently cannot be overcome with the knowledge and techniques available. This situation is due chiefly to a lack of understanding of many of the fundamental principles which govern various phases of reproduction, growth, and elaboration of the enzyme systems of the micro-organisms concerned. During the past few years, considerable progress has been made in the field of cellular biology and physiology, and our knowledge of enzymes has been appreciably extended. There is a real opportunity to apply many of these advances to the development of new and improved methods for the fermentation of corn and corn products for the production of useful industrial materials.

Any discussion of fermentation processes naturally leads to a consideration of the possibilities of the application of such processes to the production of motor fuels derived from farm products, a subject which has been of great interest to many people during the past 10 years.

Civilization has been revolutionized by the development of the internal-combustion engine as a source of mobile and stationary power. In the United States, present fuel material for internal-combustion engines is practically limited to petroleum, of which our national reserves will some day be exhausted if large-scale use is continued. Petroleum reserves according to present estimates, are sufficient for only a limited period at the current rate of consumption. Newly discovered petroleum deposits are estimated as not equaling present consumption, with seemingly lessening chance of future discovery of adequate reserve replacements. Replacement fuels from other sources must eventually be developed and brought into use. The possibility of supplying such fuel requirements from annually renewable agricultural crops or crop surpluses such as corn might be of national benefit, not only for conserving present petroleum reserves, but also as a means of absorbing crop surpluses.

Motor fuels derived from corn may conceivably be used either as the main motor fuel constituent or as an addition agent to impart valuable characteristics to the fuel, such as antiknock value or increased combustibility. The market for motor fuels is extremely large. The practicability of developing such fuels from corn depends on the cost of the products so produced in relation to the present and probable future value and availability of other motor fuel materials and the properties and characteristics of the fuels so produced in relation to those of competing fuels. Although there has been much interest in the use of ethyl alcohol in motor fuel and considerable work has been done, there remain many technically and practically important points yet to be established conclusively.

Alcohol blends have been used to a considerable extent as motor fuels in foreign countries. In such countries, however, costs of motor fuel are much higher than in this country; petroleum supplies are inadequate; motor users are relatively much fewer; automobile engines are small; national self-sufficiency is a very important factor. On the other hand, their raw materials for alcohol production cannot, in many instances, be increased extensively beyond requirements for food and feed and industrial and beverage use. Use of alcohol in motor fuel has been subjected to trial marketing in this country. These attempts, however, have not been very successful because of a number of factors, chiefly concerned with inadequate preliminary evaluation and understanding of the technical, economic, and marketing problems involved.

Present supplies of industrial alcohol in this country are produced almost entirely from molasses or from petroleum gases. The alcohol now produced from corn or its derivatives goes into either potable products or special, relatively high cost uses. It is particularly important to establish the cost of producing the type of product suited to motor fuel use, since there has been a great divergence of opinion on this. Such cost data as already exist are either not generally available or are not generally accepted as authoritative. In addition, there are several possible economies and simplifications in processing corn to produce motor fuel alcohol, that have not been adequately investigated.

Often an important factor in the cost of a primary product of fermentation is the credit obtainable from byproducts such, for example, as the feed byproduct from corn fermentation. The value of the latter has heretofore not been adequately determined. Also, the development of a suitable and cheap denaturant for use in alcohol needs investigation.

In addition to the use of corn for producing liquid fuels, there are some possibilities in the utilization of low-price, low-grade, surplus corn in the production of gaseous and solid fuels. At least one large manufacturer of engines for farm use is much interested in the possibility of using solid fuels from the farms as a source of motive power, particularly in Diesel engines. However, the production of gaseous and solid fuels should, for the present, center primarily on use of relatively very low-valued materials, such as agricultural residues of stalks, cobs, straw, and the like.

Adaptation of liquid, solid, or gaseous motor fuels from agricultural products to practical use will require laboratory and field tests of these fuels in engines and vehicles in order to determine economy, power, acceleration, effect on engine wear or corrosion, antiknock qualities, practical combustion characteristics, and other properties in actual use. Work on this subject so far done has been limited to brief and in some respects inconclusive studies on simple alcohol-gasoline mixtures.

Scarcely any knowledge is available on the fundamental properties of motor fuels derivable from corn, which are of importance in producing, distributing, storing, handling, and adapting these fuels to practical use. For example, there has been but little work done (1) on the solubility of alcohols in different types of hydrocarbons as influenced by the presence of small amounts of water and of so-called blending agents which act to prevent separation of alcohol from gasoline and (2) on the vapor pressures at different temperatures of various mixtures of alcohols with different types of hydrocarbon fuels, a matter of great importance in relation to "vapor-lock" in practical use. Laboratory investigation is needed on the problem of cheaper and more suitable denaturants specifically designed for fuel alcohol. The energy relations and requirements in recovery of fuel materials from agricultural products and in their use as fuels need further theoretical study and correlation in order to determine the ultimate practical possibilities. Especially in developing solid fuels, colloidal properties are of great importance.

The achievement of a replacement fuel industry on a national scale would very likely involve certain economic changes, and such an industry should be extended carefully through the resulting period of change and development. Introduction of new types of fuels may considerably complicate present methods of distribution and many require standardization of all fuels sold for automotive purposes, because of the varying costs involved in the production of the several components of the fuels as well as in the production of any single component at different geographical points. Such production cost variations will be particularly important in fuels from agricultural sources, which probably cannot be limited to a single agricultural commodity but may be produced from any starch or sugar material or even from wood. The research should be applicable with modifications to a variety of materials. Relative costs of fuels produced from high-grade or low-grade corn or similar raw material must be established. Cost of production of agricultural fuels must be related to a common basis so as to equalize geographic or varying raw material limitations. The problem of commercializing new fuels in such a manner as not to disturb unduly the existing industry contains elements of special difficulty.

Any program which contemplates the effective extension of industrial uses of corn must involve large quantity processing of this agricultural commodity and its products. Laboratory studies furnish the ground work and fundamentals but cannot usually be translated directly to large-scale processes. Semi-commercial or pilot plant investigations furnish the logical intermediate step. The behavior of material in large quantities often differs markedly from its behavior in small quantities. Heat transfer, mixing, nature of equipment material, and other factors all present different conditions in the test tube than in large scale equipment. It is apparent that a new process or product developed in the laboratory requires considerable further investigation before it can be submitted to industry as a workable proposition.

Pilot plant research is necessary not only to solve technical difficulties but it is invaluable in obtaining data concerning the cost of operation of a new process or the cost of production of a new product. Regardless of the nicety of a process or the desirable characteristics of a new product, industry cannot be expected to take on the new development unless it presents a favorable economic picture. If cost data can be provided which indicate a reasonable chance that a new development may successfully meet competition, then the probability that industry will adopt the development and prosecute it in such a manner as to rapidly increase the industrial consumption of corn is much more likely.

In research on corn products, the competitive relation of corn to other agricultural raw materials must be considered, as well as the conpetition of these agricultural products with those secured by methods of synthetic chemical manufacture using raw materials which do not come from agriculture. The competitive position of cornstarch will illustrate the complexity of the economic-technologic problems which must be faced in determining any research program. While the starches isolated from different plants (cornstarch, potato starch, wheat starch, rice starch, tapioca, etc.) differ in physical properties, they are fundamentally of the same chemical constitution. It is possible to modify each starch to such an extent that it acquires the physical properties desired for a large number of uses. Price largely determines the market outlets for the different starches except for a limited number of special uses. The adhesive on postage stamps is an exception of this type, tapioca and sweetpotato starches having advantages over all others. For use in certain rubber products, cornstarch has the advantage. Potato starch is used in Germany in the same products for which cornstarch is used in this country, entirely because of agricultural price relationship. Still another factor which must be taken into consideration is the impact of the use of imported starches on the utilization of cornstarch in this country.

Various surveys must be carried out to secure the necessary information for evaluating the different factors affecting the utilization of corn and its derived products. In order to establish the feasibility and desirability of new uses for corn, data must be available concerning such factors as location, quantity, quality, and condition of the materials to be used, the effect of such usage on other uses, on the use of other farm commodities. Much of this data is being collected by various governmental agencies. However, this information must be assembled, interpreted, and evaluated in the light of the specific problems connected with utilization investigations. Field surveys of marketing, handling, processing, and consumer requirements are essential for the determination of the practicability of any use discovered or for the development of such use along practical lines. Research of this type is today considered essential in well-ordered industrial product development.

The foregoing represents an outline of the problems which the Northern Regional Laboratory will investigate in order to develop new and wider industrial outlets for corn and corn products. From the discussion, I hope that you have gained a broad view of the main lines of attack which we expect to follow. I am sorry that time will not permit similar summaries dealing with wheat and agricultural residues, both of which are so important in the agricultural economy of the Northern region, as well as a broad review of the research programs of the other three regional laboratories.

Let me say now to you who have special interest in and enthusiasm for the development of new and wider outlets for the products of the farm that the success of the four new laboratories will depend to a great degree upon the extent of research cooperation. Experience in the preparatory work going on since the laboratories were authorized indicates this cooperation from industry, State research institutions, and other organizations will be all we could wish for. The staffs of the laboratories will keep their doors open to give out information and to receive suggestions. I hope all of you will consider this a standing invitation to continue to take part in this important research venture.

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